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EVALUATING *ERIOGONUM CORYMBOSUM* TOLERANCE TO FREQUENT
IRRIGATION AND EVALUATING ITS SIGNIFICANT MORPHOLOGICAL
VARIATIONS FOR POTENTIAL CULTIVARS

by

Graham Hunter

A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Plant Science

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2013

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ABSTRACT

Evaluating *Eriogonum corymbosum* Tolerance to Frequent Irrigation and Evaluating Its
Significant Morphological Variations for Potential Cultivars

by

Graham Hunter, Master of Science

Utah State University, 2013

Major Professor: Roger K. Kjelgren
Department: Plants, Soils and Climate

Two separate experiments were designed to assess the value of Lacy Buckwheat (*Eriogonum corymbosum* Benth) as a low water landscape plant. Low water use landscapes can contribute to water conservation in arid climates. Developing a palette of plants that are both attractive and drought tolerant can promote the acceptance of low water use landscapes as an alternative to the traditional bluegrass landscapes of the Intermountain West. *Eriogonum corymbosum* is an attractive subshrub species native to low rainfall areas of the Colorado Plateau. A strip plot design containing four repetitions with four randomly assigned plants each of *Eriogonum corymbosum*, *Eriogonum thompsoniae* and the control species *Cornus sericea* ‘Kelseyi’ was established to determine *E. corymbosum* tolerance to frequent irrigation. Two water treatments were assigned to the repetitions for each species. One treatment was watered by a drip irrigation system with sixteen liters of water every three days; the other treatment was not watered. Stomatal conductance (G_s) and plant water potential were assessed weekly for

each species from June through August for the years 2009 and 2010. In 2009 and 2010 both *Eriogonum* accessions showed no significant difference with the water treatment/accession interaction. Neither *E. corymbosum* accession exhibited differences in stomatal conductance or water potential between the wet and dry treatments for the length of study season over both years. *Cornus sericea* ‘Kelseyi’ showed less ability to withstand the prolonged dry frequencies.

Eriogonum corymbosum has many aesthetic qualities, in addition to being drought tolerant, such as long duration late season blooming of yellow and white flowers, and an appealing hemispherical crown shape. A second study was designed to investigate the morphological diversity of thirteen *Eriogonum* accessions collected in the state of Utah and established in a common garden. Nineteen different variables made up of both quantitative and qualitative morphological characteristics comprised of leaf, canopy and floral characteristics were selected to compare between and within accessions. These characteristics were observed or measured, then used in a Multidimensional Preference analysis (MDPREF) to facilitate the selection of potential cultivars. The MDPREF is useful in selecting accessions with unique combinations of ornamental characteristics that could have a marketable advantage.

PUBLIC ABSTRACT

Graham Hunter

Eriogonum corymbosum (Lacy Buckwheat) is an attractive subshrub species native to low rainfall areas of the Colorado Plateau and suitable for low water landscapes in the Intermountain West (IMW). Low water use landscapes can contribute to water conservation in arid climates; developing a palette of plants that are both attractive and drought tolerant can promote the acceptance of low water use landscapes as an alternative to the traditional bluegrass landscapes of the IMW. In 2007 a strip plot design containing four repetitions with four randomly assigned plants each of *Eriogonum corymbosum*, *Eriogonum thompsoniae*, and the control species *Cornus sericea* ‘Kelseyi’ was established to determine *E. corymbosum* tolerance to frequent irrigation. Two water treatments were assigned to the repetitions for each species. One treatment was watered by a drip irrigation system with sixteen liters of water every three days; the other treatment was not watered. Stomatal conductance (G_s) and water potential were assessed weekly for each species from June through August for the years 2009 and 2010. In 2009 and 2010 both *Eriogonum* accessions showed no significant difference with the water treatment/accession interaction. Neither *E. corymbosum* accession exhibited differences in stomatal conductance or water potential between the wet and dry treatments for the length of study season over both years. *Cornus sericea* ‘Kelseyi’ showed less ability to withstand the prolonged frequencies without irrigation.

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Graham Hunter

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CHAPTER I

INTRODUCTION AND OBJECTIVES

Drought cycles and population growth in the arid IMW demand a more sustainable approach for irrigated landscape watering practices. Between the years 2000-2010 Utah's population increased by 23%. This is typical growth rate for most of the intermountain states. Nevada, the driest state in the union, has seen its population grow by 35% over the same period making water conservation an urgent issue (United States Census Bureau 2011). Irrigation management is one critical aspect of landscape water conservation. Efficient irrigation in traditional IMW landscapes requires a considerable investment in knowledge: when to water, how much to water, seasonal adjustments and water distribution efficiency all require close management. This can be difficult for the average homeowner to sustain. One way to simplify the process is to reduce and rethink the way we use water in the landscape.

Low water landscaping is more sustainable than traditional landscapes requiring regular irrigation. Its sustainability comes from using plants and techniques that are adapted to local conditions. Large turf areas no longer drive the landscape system and use most of the resources. Rather, with low water landscapes, the plants are genetically predisposed to the harsh climate and soils of the IMW. Many have developed to survive moderate periods of drought. They often have deep extensive root systems, and small leaves that capture less sunlight. The leaves would typically reflect more sunlight by having blue-green or silver pigmentation, dense trichomes, or they may have a waxy outer layer, all of which help reduce plant transpiration needs in the harsh climate where they evolved (Mee and others 2003). Low water landscapes also conserve water through

proper water management. Supplemental irrigation in low water landscapes is typically only needed and applied during the heat of the summer, which eliminates the need to adjust the frequency of irrigation during the cooler spring and fall seasons. Irrigation controllers can be set to operate based on hydrozones which reflect the actual plant water requirements. Water distribution uniformity is no longer a critical issue as the large root systems of plants adapted to local conditions can pick up the water from a point source and redistribute it internally. Owner input and knowledge of irrigation controllers can be reduced to knowing when it gets hot, turn the system on, and when it cools off, turn the system off.

Not only do low water landscapes conserve water, but they can reduce maintenance and promote healthier plants. The overall dryer soil conditions in low water landscapes help reduce weed seed germination (Kratsch 2010). Irrigation systems are used less and tend to be simpler, with fewer moving parts, which can reduce wear and tear. The knowledge investment in low water landscapes comes up front in the design process. Key to the process is an understanding of which plants to use and matching plants with similar requirements together on the same water zones (hydrozoning).

To reduce the amount of water used in the landscapes of the IMW, a new palette of drought adapted plants is being established. The IMW has a significant resource of highly ornamental plants that come equipped with regional tolerances for local climatic and soil conditions. Organizations like Colorado's "Plant Select[®]" and Utah's "Slow the Flow" are collaborative organizations made up of educators, horticulturalists and nurseries that identify, research, and distribute these selected cultivars in the intermountain area. These plants need to be evaluated at several levels before being released commercially. How

unique are they? Are they potentially invasive? Can they be easily propagated? Can they tolerate more fertile and wetter landscape conditions? These questions and many more need to be addressed when introducing new plants to the landscape. No issue is more critical for low water landscaping than understanding the tolerance of these new plants to both drought and frequent irrigation in the landscape.

Geologically speaking, the IMW is still relatively young. As recently as 10,000-12,000 years ago western Utah and parts of Nevada were covered by Lake Bonneville and Lake Lahontan (Antevs 1948). Pollen samples recovered from the Leonard Rockshelter sediments support the rapid disappearance of these lakes brought on by climate warming and aridification of the region (Byrne and others 1979). Vast new habitats were opened for plant colonization. Diversity in ecoregions, soil types, precipitation, temperatures, and elevations, resulted in habitats that have given rise to many endemic and rare plants (Shultz 1993).

A plant's ability to adapt gave it an advantage for filling those new available niches. Plants species that experience rapid speciation have the ability to exchange genetic information with other similar species through introgressive hybridization (Grant and others 2005). Intermountain West genera like *Eriogonum* and *Penstemon*, which fit into this category, show a vast amount of morphological variation. This variation is a resource that can prove valuable in cultivar selection for landscape plants.

Plant adapt to drought in different ways. Drought avoiders may finish the reproductive cycle before water is limited. Or they may drop their leaves entirely to avoid drought induced cavitation, which could be fatal. Other plants may use drought avoidance techniques that can minimize water loss by stomatal closure, forming a cuticle layer, or

by changing their leaf shape or orientation. Physiological responses when coupled with morphological adaptations like small reflective leaves, dense pubescence, and deep taproots give plants an advantage for surviving the harsh climate of the IMW. Generally plant height increases as rainfall increases. Conversely, rainfall decreases as elevation decreases. The plant communities from the desert valleys and floors include small drought-ready perennials, shrubs, and sub shrubs that have taken full advantage of both physiological responses and morphological adaptations to survive the periodic droughts and the long, dry, hot seasons of the IMW.

However, can this same plant perform in the landscape, surviving low water conditions and still maintaining acceptable visual quality? A plant that drops its leaves to avoid drought generally doesn't make a good landscape plant. *Echinacea purpurea* is known for its ability to survive drought, but under drought conditions it survives by wilting until being watered again. This wilted visual quality would not be acceptable in a landscape (Zollinger 2006). In the same study another plant known for surviving drought, *Gaillardia aristata*, died back to the ground then regrew when watered, effectually reducing leaf area by between 50-84% of the control plant. Again, the visual quality was unacceptable as most plants did not flower as a result of the drought stress.

Eriogonum corymbosum (Lacy Buckwheat) is being propagated for commercial release as a low water ornamental plant. There is no question that its uniqueness draws interest from native plant horticulturalists and enthusiasts. But can *E. corymbosum* become a major plant for low water landscapes of the IMW and beyond, or will it be relegated to rock gardens and other esoteric uses? Two major issues confront *E. corymbosum* commercial success. What is the *E. corymbosum* tolerance of frequent

irrigation? We can assume as a desert species that *E. corymbosum* has good drought tolerance, but how will it handle the excessive irrigation that can often be the biggest issue for plant health in low water landscapes (Kratsch 2010). Is the morphologic variation between populations of *E. corymbosum* due entirely to genetics? What effect would a common environment have on the ornamentally significant morphology of several populations of *E. corymbosum* collected from across the Colorado Plateau?

OBJECTIVES

The overall objective of these studies is to assess physiological and ornamental properties of *Eriogonum corymbosum* for development of this species as a low water landscape plant.

Objective 1. Understanding *Eriogonum corymbosum* tolerance to frequent and no irrigation conditions that may limit appearance, and performance in wet, fertile, and dry landscape conditions.

Objective 2. Evaluation of ornamentally significant morphological characteristics of the collected accessions in a common garden for their landscape potential as cultivars.

CHAPTER II

LITERATURE REVIEW

The family *Polygonaceae* is comprised of 48 genera and over 1200 species. This family is wide spread mainly throughout temperate North America and is comprised of trees, shrubs, sub-shrubs, vines, and herbs. This family is divided into two subfamilies *Polygonoideae* (28 genera, 850 species) and *Eriogonoideae* (20 genera, 281 species) (Freeman and Reveal 2005). The distinction between these subfamilies is that members of *Eriogonoideae* include all the descendants from a single common ancestor (monophyletic), while members of the subfamily *Polygonoideae* do not include all the descendants of a common ancestor (paraphyletic) (Sanchez 2008). The genus *Eriogonum* (subfamily *Eriogonoideae*) is made up of annual and perennial herbs, sub-shrubs and shrubs. There are estimated to be 255 different species of *Eriogonum*, most of which are present in North America (Freeman and Reveal 2005). *Eriogonum* has proved to be a difficult genus to classify taxonomically. Flowers between taxa are often very similar and diagnostic characteristics are often variable within the species. The perennial species tend to hybridize, the resulting hybrids of which adapt to fit specialized environments often limited by soil characteristics (Welsh 1984). The subfamily *Eriogonoideae* has gone through many revisions as new information and species have been discovered.

In the context of new habitats, interspecific hybridization is an important mechanism in speciation and angiosperm evolution (Hegarty 2005). New allele combinations in these evolved species can result in plants that may adapt better to differing environmental conditions that were unavailable to their parental taxa (Rieseberg 2003). Intermountain West genera have used this to great advantage.

The family *Chenopodiaceae* has many genera that are predisposed with unique attributes for tolerance to alkaline soils and cold climate conditions. Autoploidy (multiple copies of a set of haploid chromosomes in a single parent) is common in this family, particularly in the genus *Atriplex*. Numerous *Atriplex* species are believed to have moved out of northern Mexico into newly available habitats of the IMW (Stutz 1978). Natural hybridization between several of these *Atriplex* species has occurred, giving rise to new species adapted to take advantage of the new habitats created by Lake Bonneville's withdrawal.

Other IMW genera have exhibited similar rapid speciation. Herbarium collections show that southern Utah is an important region for diversity and speciation in the genus *Sphaeralcea* (Atwood and Welsh 2002). Morphological, and hence species, distinctions of these taxa are obscured by overlapping characteristics. Many of these obscure distinctions are a result of hybridization between taxa (Kratsch and others 2010).

The genus *Penstemon* is undergoing rapid speciation. *Penstemon* (*Plantaginaceae*) is the largest genus in North America. It is made up of over 270 different species, with over 100 species in Utah (Wolfe 2002). The central Rocky Mountain region and the Columbia River Basin are considered the center of origin for this genus. *Penstemon* shows high variability in both floral and vegetative makeup (Wolfe and others 2006). This diversity is a result of evolutionary adaptation to specialized pollinators and ecological niches.

The genus *Eriogonum* shares many characteristics of the before-mentioned genera. *Eriogonum* species, with their tolerance for saline and drought conditions, were well positioned to take advantage of the climatic and geographic changes of the late tertiary period. Of the 250 recognized species of *Eriogonum* in North America, 60 species are in

the state of Utah, at least 14 of them endemic (Shultz 1993). *Eriogonum* species range in elevation from the highest mountain tops of the Sierra Nevada Mountains to below sea level in Death Valley. There are representative species in every western state of the continental US, as well as many Great Plains and Southeast states.

Eriogonum corymbosum is a good example of a plant species undergoing rapid speciation. The Colorado Plateau has been suggested as the center of origin for *E. corymbosum* (Ellis 2009). There are eight recognized varieties in the *E. corymbosum* complex. *E. corymbosum* var. *aureum* is located on the edge of the Mojave Desert, the Great Basin, and the Colorado Plateau, which is on the outer edge of the species range. Recent genetic sequencing experiments have shown that variety *aureum* has more shared characteristics with *Eriogonum thompsoniae* than it does with other *E. corymbosum* varieties. Populations of var. *aureum* proved to be the most genetically diverse, as shown by comparing AFLP profiles and chloroplast DNA sequences from population selections across the range of the *E. corymbosum* complex (Ellis 2009). *E. corymbosum* var. *nilesii* is a disjunct variety in the Mojave Desert, completely outside the normal species range. It proved to be the least genetically diverse variety in the Ellis study. It also was established in the analysis to be the closest *E. corymbosum* relative to var. *aureum*, suggesting that var. *aureum* is the hybrid of var. *nilesii* and *E. thompsoniae*. This would imply a history of hybridizing with a different buckwheat species. Morphological evidence has also alluded to hybrid combinations involving *E. corymbosum* and other species (Welsh 1984). Morphological evidence suggests that certain varieties of *E. corymbosum* and the species *E. microthecum* were shown to cross with *E. brevicaule*, an herbaceous sub-shrub species in the genera. This type of evidence suggests that *E. corymbosum* is a

promiscuously out-crossing species. The complicated genetics found in the whole of the *E. corymbosum* complex has resulted in significant morphological variations that need due consideration of the implications for low water landscaping.

Dr. James Reveal, throughout his career in plant taxonomy, has made significant contributions to our understanding of this complicated genus; his doctoral dissertation was a revision of the entire *Eriogonum* genus. He also revised the *E. corymbosum* complex in 2002 and 2005. He has performed chromosome counts for many *Eriogonum* species, greatly expanding our cytological knowledge in this area (Hess 1976). Dr. Reveal's contribution to research in systematic botany should not be understated. There are approximately 500 publications that he has authored or coauthored during the course of his career, many of these dealing with the family Polygonaceae.

The *E. corymbosum* Benth. complex (Eriogonoideae) is distributed throughout the Colorado Plateau and adjacent areas. The center of origin appears to be in south central Utah and radiates out into Wyoming, Colorado, New Mexico, Arizona, and Nevada (Ellis 2009). The arid to semi-arid Colorado Plateau averages around 10 inches of annual rainfall (Grahame 2002). This suits *E. corymbosum*, as it prefers areas of low rainfall, warm temperatures, and high evaporation. It also tends to populate a variety of habitats and elevations from gumbo clay hills to sandy desert floors, as well as steep mountain slopes (Reveal 1967). This species tends to proliferate in disturbed areas along roadways, but away from these unnatural conditions it is rarely the dominant species.

Reveal's landmark work covering the *E. corymbosum* complex for Flora of North America shows just how diverse the habitat is for this complex of plants (Reveal 2008). *Eriogonum corymbosum* var. *nilesii* is found at the lowest elevation of the complex at a

range from 200-900 m. It is found outside the Colorado Plateau, its normal species range, in the Mojave Desert areas around Las Vegas, Nevada, and inhabits the saltbrush communities in sandy to gravelly washes, as well as gypsum flats and mounds. It flowers on the later end of the summer between August and November, and is the most westerly located variety, with a small distribution footprint.

Eriogonum corymbosum var. *aureum* elevation range is between 1000-1100 m. It is found around the St. George, Utah area in the creosote and blackbrush communities, as well as in the juniper woodlands on the edge of the Colorado Plateau/Mojave Desert ecoregions. It is another late flowering variety, blooming between August and October. It also has a small distribution footprint.

Eriogonum corymbosum var. *glutinosum* has a much larger footprint. It extends well down into the center of Arizona, as well as through 6-8 counties in south central Utah. Along with its large footprint it also has a large elevation range, between 1200-2600 m. This variety flowers from July to October. It populates a variety of soils and exposures from sandy, gravelly or clayey flats, washes, slopes, outcrops, and cliffs, and is found in association with saltbrush, blackbrush, and sagebrush communities, as well as pinyon-juniper woodlands.

Eriogonum corymbosum var. *revealianum* overlaps the northern part of the var. *glutinosum* footprint and extends north; its footprint is small and it is infrequently found. The flowering period is between July and September. It prefers elevations between 2100 and 2800 m in gravelly to rocky clay slopes in pinyon-juniper and conifer woodlands.

Eriogonum corymbosum var. *heilii* occupies the smallest footprint and is found only in a small area of Capital Reef National Park. It populates steep rocky slopes in sub-

alpine coniferous woodlands at between 2500 and 2800 m. It flowers between July and August and is found in association with Rocky Mountain bristlecone pine.

E. corymbosum var. *corymbosum* populates the largest footprint, stretching from Wyoming to Arizona throughout all of eastern Utah and the western edge of Colorado. This range overlaps into five of the other variety footprints. It occupies sandy to gravelly or clayey flats, washes, slopes, outcrops, and cliffs. It is found in association with saltbrush, blackbrush, and sagebrush communities as well as pinyon-juniper and montane conifer woodlands. Its flowering period is between July and October and is found at elevations between 1200 and 2700 m.

E. corymbosum var. *orbiculatum* populates an area from south central Utah extending eastward into south western Colorado. It also extends south into the north central portion of Arizona. It overlaps into three footprints of other varieties. Its elevation is between 900 and 2300 m and occupies sandy to gravelly flats, slopes, washes, mixed grasslands, saltbrush, blackbrush and sagebrush communities as well as pinyon-juniper woodlands. Its flowering period is between August and October.

E. corymbosum var. *velutinum* occurs around the four corners regions of Utah, Colorado, Arizona and New Mexico. Most of the footprint for this variety is located in New Mexico and Colorado. Its flowering period is between August and October and it populates sandy to gravelly or clayey flats, washes, slopes, mixed grasslands, saltbrush and sagebrush communities as well as pinyon-juniper woodlands.

Reveal's work in identifying the eight recognized varieties of *E. corymbosum* is based on his morphological conclusions. Reveal determined that the population of *E. corymbosum* found in the Las Vegas, Nevada area was morphologically and ecologically

different from varieties *glutinosum* and *aureum* where it had been previously grouped and proposed it for a new varietal designation as *E. corymbosum nilesii* (Reveal 2002). The Vegas populations are under constant pressure from encroaching recreation, construction and development (Morefield 2007). Ellis studied the genetic affiliations of *E. corymbosum* var. *nilesii* (Ellis 2009). He examined six of the eight recognized varieties of *E. corymbosum* as well as many other related species. His studies supported Reveal's designation for var. *nilesii* and uncovered other interesting genetic relationships within the *E. corymbosum* complex, as referenced in an earlier section in this paper.

Eriogonum corymbosum landscape potential is yet to be fully recognized. It has many desirable traits that make it appealing as an ornamental (Meyer and others 2009). Its form develops early in the summer as the flower stocks start to grow, and it takes on a unique hemispherical shape. It maintains this rather coarse yet airy form the remainder of the growing season. It also has a long showy flower period that starts in late summer and extends well into the fall. The flower color varies from a brilliant yellow to shades of white—often tinged with red—which changes the blue-green vegetative form into an explosion of color. As the color fades it is replaced with an attractive rust red fall color that it maintains throughout the winter, granting the plant three seasons of interest in the landscape. As *E. corymbosum* is native to areas that receive around 10 inches of annual rainfall it performs very well in low water conditions.

There are many things to consider when selecting a cultivar for potential use as a landscape plant. When selecting Bigtooth maple, Richards used a three part evaluation which began with a visual/aesthetic evaluation (Richards 2010). Aerial photography was used to find, select and pinpoint GPS coordinates of unique specimens based on fall color

and isolation. The specimens were then located on the ground, where the form could be evaluated. The second part of the evaluation was based on a list of criteria for function and characteristics specific to Bigtooth Maple. The criteria were habitat, disease, insect damage, quality of budwood, and layering. The third evaluation was also based on fall leaf color photos that were compared to a Munsell color chart to quantify the actual color. The trees with the most brilliant reds were then selected for cloning. Plant Select[®] uses a 12 step process for evaluation of a potential cultivar (Colorado State University, Denver Botanical Gardens 1999). The steps are:

1. Performance in a broad range of garden situations in the Central Rocky Mountain Region
2. Adaptation to the Central Rocky Mountain Region's challenging climate
3. Uniqueness
4. Resistance to pests (disease pathogens, insects, and mites)
5. Exceptional performance under low water conditions
6. Long season of beauty in the garden
7. Non-invasiveness
8. Capability of being mass produced
9. Longevity in containers (retail appeal)
10. Current availability from current propagators
11. Ease of propagation using basic propagation protocols
12. Availability of images of established specimens in landscapes (for publications)

Anecdotal evidence suggests that *E. corymbosum* performs well with regard to this list. The biggest unanswered question is in regard to ease of propagation. *Eriogonum corymbosum* is easily propagated from seed. However, the diversity in flower color within a population suggests that producing a consistent flower color from seed is, for the most part, unlikely. The exception is the yellow flowered *E. corymbosum* var. *glutinosum*. This variety has been commercially released in the trade. Propagating *E. corymbosum* from cuttings has proved problematic and needs further research.

Eriogonum corymbosum is highly drought tolerant and can survive in most landscape conditions with no supplemental watering (Meyer and others 2009). The genus *Eriogonum* has a slender to stout taproot (Reveal 2008). *Eriogonum corymbosum* also has leaves that have adapted to conserve water loss. They are generally small, have a lighter blue-green color, and thick trichomes on both top and bottom. Anecdotal evidence from both the common garden study and the water relations study indicate that *E. corymbosum* may be sensitive to heavy wet soils, particularly in the spring. After three consecutive wet springs in northern Utah, significant losses were sustained in the *E. corymbosum* studies at the Greenville farm, which has a deep heavy silt loam soil. There is evidence that other Colorado Plateau plants have similar problems. Penstemon species have a tendency to develop vascular wilt diseases that are aggravated by overwatering (Meyer and others 2009).

CHAPTER III

EVALUATING *ERIOGONUM CORYMBOSUM* TOLERANCE TO FREQUENT
IRRIGATION

ABSTRACT

Low water use landscapes can contribute to water conservation in arid climates. Developing a palette of plants that are both attractive and drought tolerant can promote the acceptance of low water use landscapes as an alternative to the traditional bluegrass landscapes of the IMW. *Eriogonum corymbosum* is an attractive subshrub species native to low rainfall areas of the Colorado Plateau. In 2007 a strip plot design containing four repetitions with four randomly assigned plants each of *Eriogonum corymbosum*, *Eriogonum thompsoniae* and the control species *Cornus sericea* ‘Kelsey’ was established to determine *E. corymbosum* tolerance to frequent irrigation. Two water treatments were assigned to the repetitions for each species. One treatment was watered by a drip irrigation system with 16 liters of water every three days. The other treatment was not watered. Stomatal conductance (G_s) and water potential were assessed weekly for each species from June through August for the years 2009 and 2010. In 2009 and 2010 both *Eriogonum* accessions showed no significant difference with the water treatment/accession interaction. Neither *E. corymbosum* accession exhibited differences in stomatal conductance or water potential between the wet and dry treatments for the length of study season over both years. *Cornus sericea* ‘Kelsey’ showed less ability to withstand the prolonged frequencies without irrigation.

INTRODUCTION

Drought cycles and population growth in the arid Intermountain West (IMW) demand a more sustainable approach for irrigated landscape watering practices. Irrigated urban landscapes can consume up to 60% of municipal water supplies in the IMW (Kjelgren 2000). Water conservation in irrigated urban landscapes is a critical aspect of managing growth and drought cycles (St. Hilaire 2008).

Low water landscaping is an alternative, sustainable approach to water conservation in irrigated urban landscapes. Low water landscaping is careful design of irrigated landscapes for non-uniformity of surface cover using fewer and yet more drought tolerant plants (Mee 2003). Native IMW plants from lower elevations are typically drought tolerant and many aesthetic qualities suitable for urban landscapes. Drought tolerant plant species from the IMW often have deep, extensive root systems and fine-textured small leaves that intercept less sunlight due to attractive blue-green or silver pigmentation that reflects more shortwave radiation, dense trichomes, or a waxy cuticle to reduce transpiration and soil water use. These plants are not commonly used because of limited production in the nursery trade and limited information on proper management in the landscape (Meyer and others 2009).

Low water landscapes also conserve water through proper management. Supplemental irrigation in low water landscapes is typically only needed and applied during the heat of the summer which eliminates the need to adjust the frequency of irrigation during the cooler spring and fall seasons (St. Hilaire 2008). Irrigation controllers can be set to operate based on hydrozones consisting of plants with similar water requirements, such as drought tolerant IMW natives. Water distribution uniformity

is a much less critical issue as the large root systems of plants adapted to local conditions can take up water from a point source input and redistribute it internal to the plant and root system. Owner input and knowledge of irrigation controllers for low water landscapes can be potentially reduced to knowing when it gets hot, turn the system on, and when it cools off, turn the system off (Kilgren 2010).

To conserve water through increased use of low water landscapes in the IMW a new palette of drought adapted native plants is being established (Mee 2003) (Meyer and others 2009). These plants need to be evaluated at several levels before being released commercially. How unique are they? Are they potentially invasive? Can they be easily propagated? Can they tolerate more fertile and wetter landscape conditions? These questions plus many more need to be addressed when introducing any new plants to the landscape. No issue is more critical for low water landscapes than understanding tolerance of these species to both drought and, most importantly, frequent irrigation in the landscape, as for many of these species excess root water can often be lethal due to disease.

The IMW has many ecological niches due to steep elevation gradients, recent glaciation, and a wide variety of parent materials that promote plant colonization of new ecological niches and subsequent speciation. This diversity in ecological niches has resulted in specialized habitats containing many endemic and rare plants (Shultz 1993).

A plant's ability to quickly adapt gives it an advantage for filling those newly available niches. Plants species that experience rapid speciation have the ability to exchange genetic information with other similar species through introgressive hybridization (Grant and others 2005). Intermountain West genera like *Eriogonum* and

Penstemon, which fit into this category, show a vast amount of morphological variation (Welsh 1987). This variation is a resource that can prove valuable in cultivar selection for landscape plants.

Eriogonum corymbosum is a shrub endemic to very dry habitats in the Colorado Plateau region of the IMW. *Eriogonum corymbosum* has many aesthetic qualities in addition to being drought tolerant, such as long duration late season blooming of yellow and white flowers, and an interesting hemispherical crown shape (Reveal 2008).

Eriogonum corymbosum has great potential for commercial release as a low water ornamental plant. There is no question that its uniqueness draws interest from native plant horticulturalist and enthusiasts. But can *E. corymbosum* become a major plant for low water landscapes of the IMW and beyond or will it be relegated to rock gardens and other esoteric uses? Water demand and irrigation are overall issues which need to be understood before it can be introduced into the landscape. *Eriogonum corymbosum* needs irrigation during production and establishment in landscapes, and may often be placed in zones that receive much more frequent water from irrigation than it would see in its native habitat. What is the *E. corymbosum* tolerance of frequent irrigation? We can assume as a desert species that *E. corymbosum* has good drought tolerance, but will it be able to maintain acceptable appearance under limited and no water situations (Kratsch 2010)? Anecdotal evidence suggests that *E. corymbosum* is susceptible to high soil moisture conditions. It suffers high mortality rates when watered too often or when soil remains saturated for extended periods.

MATERIALS AND METHODS

This study investigated the effect of wet and dry soil conditions through supplemental irrigation and no irrigation on growth and gas exchange of two *Eriogonum* species and a non-drought tolerant control. *Eriogonum corymbosum* (crisp leaf buckwheat), *Eriogonum thompsoniae* (Thompson's buckwheat), and *Cornus sericea* 'Kelseyi' as a non-drought tolerant control (*C. sericea* is native to riparian IMW habitats and 'Kelseyi' is a dwarf form common in the nursery industry) were randomly assigned to blocks. This study was conducted at the Utah State University Greenville Experimental Farm in North Logan, Utah. Greenville Research farm in North Logan, Utah (41° 45' N and 111° 48' W); soil is a Millville silt loam (coarse-silty, carbonatic, mesic Typic Haploxerolls) uniform depth with a pH of 7.8-8.2. Field capacity and wilting point of the soil were 0.25 cm cm⁻¹ and 0.10 cm cm⁻¹, respectively (Or 1990). This is a very deep soil that allows a large rooting volume for species with deep roots. The experiment was repeated during 2009 and 2010 in late June, and again through the month of August in both years. Rainfall, temperature, and humidity data was collected from a nearby weather station (model ET106, Campbell Scientific, Logan, Utah).

Eriogonum corymbosum (crisp leaf buckwheat), *Eriogonum thompsoniae* (Thompson's buckwheat) and *Cornus sericea* 'Kelseyi' (Kelseyi's Dogwood) were used in this experiment. The two buckwheat species were obtained from the Forest Service Shrub Science Lab in Provo, Utah for the use in this experiment. The accession collection sites were from areas in south central Utah: *E. corymbosum* Long Canyon switchbacks (N 37° 51' 10", W 111° 18' 45", elevation 1729 m, average maximum temperature 16.4 C, average total precipitation 27.5 cm (Western Regional Climate Center 2010), and *E.*

thompsoniae near Wire Mesa by Rockville, Utah (N37° 9'41", W133° 01' 54" elevation 1386 m, Average Max. Temperature 23.8 C, Average Total Precipitation 37.9 cm [WRCC 2010]).

In the fall of 2006 the plants were moved from 5 inch Roottrainers[®] into four liter containers. They were allowed to fill out these pots before planting into the experimental plots in spring 2007. *Cornus sericea* was obtained from local nursery in four liter containers and planted in the experimental plot at the same time as the other species. Six plants per species were randomly assigned within each row at 2 m. Between row spacing was set at 1.5 m. The plot was watered with a separate irrigation system as needed for establishment. The study area was inter-planted with blue grama (*Bouteloua gracilis*) to constrain lateral root development by the study species. A ring of bare soil of approximately 60 cm was kept vegetation free around each study plant to avoid competition with the grass for water. No plant was fertilized after planting.

Two different irrigation frequencies were used to determine the optimum amount of irrigation for healthy plants:

- Water applied every three days.
- No supplemental water applied.

This experiment was set up as a strip plot design. Separate drip irrigation zones, controlled by separate valves, were provided for the treatment receiving water. The accessions were randomly assigned within an irrigation treatment which consisted of one row. Each irrigated plant had two 4 liter per hour emitters per plant. Run times were two hours per watering so that each plant received 16 liters at each watering, ensuring that the root zones were completely refilled with water.

Stomatal conductance

In 2009 and 2010 the experiment was started in late June and again ran through the month of August. Stomatal conductance (G_s) was measured with a leaf porometer (model SC-1 Decagon Devices, Pullman, Washington). Stomatal conductance is a sensitive measure of water stress and is a proxy for photosynthesis, and was used to assess potential effects of water stress on gas exchange. Initial measurements were a dawn-to-dusk measurement regime that was accomplished by selecting four representative plants from each accession and species, then taking four full sun measurements per plant once every two hours over the day. Measurements started at 6:30 a.m., and final readings began at 6:30 p.m.

Subsequently, weekly G_s measurements were collected for four randomly selected plants per accession for each of the two irrigation treatment. Three readings from healthy sun exposed leaves were taken per plant. If the readings were not within $100 \text{ mMol m}^{-2}\text{s}^{-1}$ of each other more readings were taken until that requirement was met. The measurements were taken starting at roughly 1:00 p.m.; the exact time varied with the amount of time it took to calibrate the porometer, which was done by placing the porometer under field condition to equilibrate with climatic conditions for 30 minutes prior to calibration. The porometers were then calibrated following specific procedures provided by Decagon Devices. It is important to note that the calibration process for the instrument changed as per manufacturer's specification both within the 2009 season and the 2010 season. It was initially recommended that calibration would be done by the manufacturer one time per year. This changed early in the season to calibrating every time the device was plus or minus 10% of $240 \text{ mMol m}^{-2}\text{s}^{-1}$. In 2010 the process was

again changed to calibrating the device in the field after it sat a field conditions for 30 min every time the device was used. The calibration process received a software upgrade that greatly simplified the process by walking the user through each step every time it was performed.

Water Potential

Water potential was measured with a Scholander-type pressure chamber (Model 4000, PMS Instrument Company, Albany, Oregon). Leaf (*Cornus*) and flower stalk (*Eriogonum*) samples were collected pre-dawn. Immediately after cutting the samples were wrapped in aluminum foil, sealed in zip lock bags and placed in a cooler with ice where they were held until measurements took place. Approximate time of measurement was recorded. Before inserting samples into the pressure chamber they were wrapped in plastic wrap. Leaves were not pressurized any faster than 0.01 MPa/second to avoid measurement artifacts.

Data Analysis

The experiment was a strip-plot design. Stomatal conductance and water potential were plotted against time for the three accession and the two water treatments with four replications (Sigmaplot 11.2, Germany). Rain fall was plotted to account for confounding effects due to weather. Differences between water treatments and accessions/species for water potential and stomatal conductance data were analyzed with PROC MIXED (Ver. 9.2, SAS Inc., Raleigh, North Carolina) to generate an ANOVA for a strip-plot design. Data with significant differences ($P=0.05$) with the water treatment/ accession interaction were analyzed with PROC MIXED using least-squares means for means separation.

Stomatal conductance was plotted against local atmospheric vapor pressure deficit (VPD) at the time of measurement to assess if dry air was regulating transpiration.

RESULTS AND DISCUSSION

In 2009, northern Utah experienced a wetter spring and correspondingly lower temperatures than average, with this pattern continuing into late June and resulting in a short research season (Figure 1). Temperatures remained lower than average for the research season, approximately 2.8° C cooler than the average for June, 1.5° C for July and 2.1° C for August. There were no rain events after late June until August 8 and August 15 where very small amounts of rain fell (5 and 2 mm, respectively). We ended data collection in late August after a three day rain event tallied 21 mm. In 2010, research season rainfall was below average, but the rain came late in June and again in late August, resulting once again in a short research season. Temperatures for the research season were again lower than average, approximately 2.1° C cooler than the average for June, 1.2° C for July and 1.9° C for August (The Weather Channel, LLC 2012). Rain fell on 6 different occasions during the 2010 research season. Early in the season there was a 3 day accumulation of 5 mm of rain. All the other rain events measured 0.5 mm, which had no effect on available plant water until 21.1 mm of rain fell between August 27 and August 30, forcing termination of the study.

In 2009 and 2010 both *Eriogonum* accessions showed no significant difference with the water treatment/accession interaction (Figure 2). Neither *E. corymbosum* accessions exhibited differences in stomatal conductance between the wet and dry treatments for the length of study season over both years. The only exception was in mid-June 2009 when non irrigated *C. sericea* was significantly lower than the irrigated *Cornus* plants. Relative

to *C. sericea*, both *Eriogonum* species recorded extremely high stomatal conductance numbers. In 2009 the *E. corymbosum* recorded numbers as high as $700 \text{ mMol m}^{-2}\text{s}^{-1}$ and the *E. thompsoniae* accession exhibited values around $600 \text{ mMol m}^{-2}\text{s}^{-1}$ on a consistent basis over the season. By contrast, *Cornus* individuals averaged closer to $350 \text{ mMol m}^{-2}\text{s}^{-1}$. In 2010 there were similar results, but with *E. thompsoniae* exhibiting the highest numbers. In both years there is a trend in all three species to have the highest stomatal conductance in the earlier part of the season and a significant drop during the latter.

Similar to stomatal responses, in 2009 neither accession showed significant decreases in predawn water potential among treatments throughout the experiment, indicating the plants with no irrigation showed no signs of water stress. Water potential values for *E. corymbosum* and *E. thompsoniae* ranged between -0.4 and -0.9 MPa. Similarly, *Cornus sericea* ‘Kelsey’ showed water potential values between -0.5 and -0.9 MPa, and showed less ability to withstand the prolonged frequencies without irrigation. In 2010 the results were similar with water potential values staying within the same ranges for all three species. There were no significant differences between treatments for any of the three species. It is interesting to note that morphological differences were also apparent between the well watered *C. sericea* and the no water treatment. The no water treatments showed considerable leaf folding, red leaf coloration, the beginning of margin burn and serious insect damage (margins had been eaten) that was not displayed in the well watered treatment.

While stomatal conductance of the two *Eriogonum* species was consistently higher than that of *Cornus*, their stomatal aperture was also more sensitive to dry air. While there was substantial scatter for each species below an upper threshold, the maximum

value of stomatal conductance for any given VPD decreased as the air became drier with increasing air temperature. This upper threshold was particularly pronounced for both *Eriogonum* species. This same pattern was repeated for both the well watered and the non-watered treatments, suggesting that *Eriogonum* maximizes gas exchange when evaporative demand is low, but restricts stomatal opening and gas exchange at high evaporative demand to minimize soil water depletion.

The leaves of *E. corymbosum* and *E. thompsoniae* are quite different from one another (Table 1). The *E. thompsoniae* leaf is close to 25% larger than *E. corymbosum*, and has a long petiole not found in *E. corymbosum*. There is a difference in color, as *E. thompsoniae* has a green hue to its foliage and *E. corymbosum* has a blue-green hue. Scanning electron micrographs (Figure 3) reveal *Eriogonum* leaves well adapted to low water conditions. The lower side of the leaf is covered with thick pubescence, while on the upper side the pubescence is much lighter. The pubescence on the lower side is so dense it is impossible to see the stomata while the topside pubescence is less dense and stomata are visible, indicating that both species are amphistomatous. Transpiration is effectively reduced by the thick mat-like trichomes on the leaf underside where stomatal density is likely to be higher, allowing for this species' survival through periods of water stress with no deleterious effects. Amphistomatous plants are characterized by inhabiting high light intensity environments, having high stomatal conductance rate and high photosynthesis rates (Mott 1991). *Eriogonum* uses this to its advantage by building its carbon chains quickly via a high rate of photosynthesis when water is available.

Given that *E. corymbosum* is a desert species accustomed to far greater extremes in temperatures and periods of drought than it was exposed to in our experimental plots

located in northern Utah, it was not surprising to find no significant difference with the water treatment/ accession interaction. Soil of the experimental site was a deep silt loam soil capable of holding up to 15% available water between field capacity and wilting point (Or 1990). High water holding capacity soil, plus *E. corymbosum* as a drought tolerant species, gives many different adaptive mechanisms to cope with water stress. Based on anecdotal observation, it has a deep taproot which allows for exploiting a large soil volume. *Eriogonum corymbosum* also has an unusual method to minimize solar leaf exposure and thus heating. Early summer it produces flower stalks that elongate well before flower development. In both accessions, by late July to early August, these stalks are dense enough to reduce incident radiation and remain so for the rest of the growing season. The long green flower stalks may be photosynthetic, which could help explain the ability of *Eriogonum* to continue to photosynthesize even when there are so few leaves that are not obscured by the flower stalks. The crowns of the *E. thompsoniae* accession were not as dense as the *E. corymbosum* accession but dense enough to make it difficult to find leaves with full sun exposure for proper stomatal conductance readings. There also appears to be some older leaf shedding, more so with *E. thompsoniae*. Both accessions produce mats of abaxial trichomes which reduce water loss by creating a boundary layer of higher relative humidity next to the leaf which lowers water evaporation. Additionally, trichomes moderate leaf temperature through shading and reflectance. Both accessions also have trichomes on the adaxial surface of the leaf; however, they are considerably less dense.

Given the deep soil of the study site, soil structure, and hence soil water holding capacity, and the morphological and genetic predisposition to drought tolerance of these

Eriogonum species even an extreme dry season would likely not result in big differences in physiological performance. *Cornus Sericea*, however, would likely show more significant differences during an extreme dry season. It is surprising that there was no effect on either *E. corymbosum* accession with the every three day water interval.

Anecdotal evidence suggests there may be a negative effect associated with overwatering many drought adapted species (Mee 2003) (Meyer and others 2009). As an ornamental plant in a landscape setting it is likely to be exposed to considerably more water than it would get in its native habitat.

Mortality rates for the experimental plots were very high over the period of the study. These high numbers reflect at least two different impacts: the high water holding capacity of the soil in the study plots and the uncharacteristic wet springs associated with the period of the study. Mortality occurred during spring where the whole plant was wetted and pathogens at the root crown were promoted. With the onset of seasonal drought, mortality ceased. It appears that the drip irrigation added during the course of the study, where water is added directly to the roots and the foliage or base of the plant is not wetted, did not have a definitive effect on mortality.

TABLE 1. Leaf properties, plant size and mortality of *Eriogonum corymbosum*, *E. thompsoniae*, and *Cornus sericea* ‘Kelseyi’.

	Leaf length (mm)	Leaf width (mm)	Leaf Area (mm ²)	Petiole (mm)	Plant width (mm)	Plant height (mm)	Mortality % watered	Mortality % non-watered	Mortality % total
<i>E. corymbosum</i>	24.8	13.3	2.7	4.9	1039	421	41	38	40
<i>E. thompsoniae</i>	33.7	20.4	10.25	31.3	1179	480	67	63	67
<i>C. sericea</i>	58.9	32.2	20.7	10	489	347.5	0	0	0

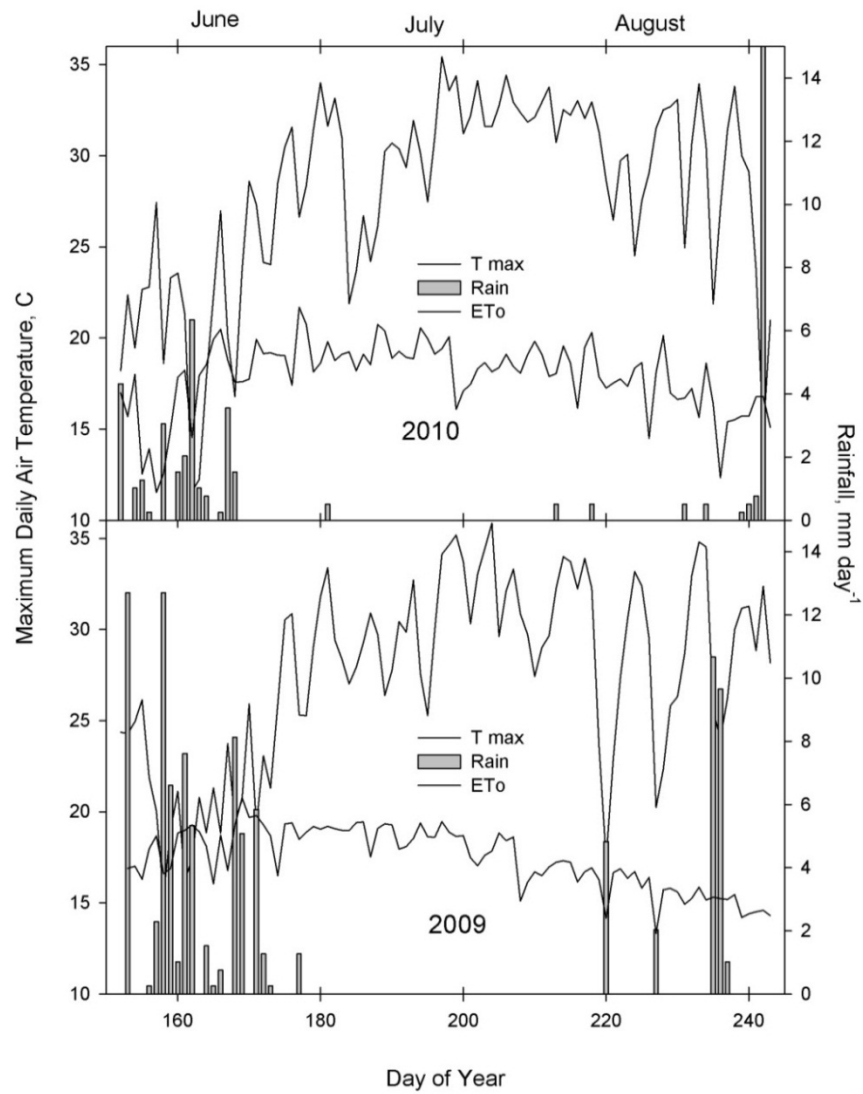


Figure 1. Rainfall, maximum temperature, and reference evapotranspiration (ETo) for the Utah State University Greenville research farm for 2009 and 2010.

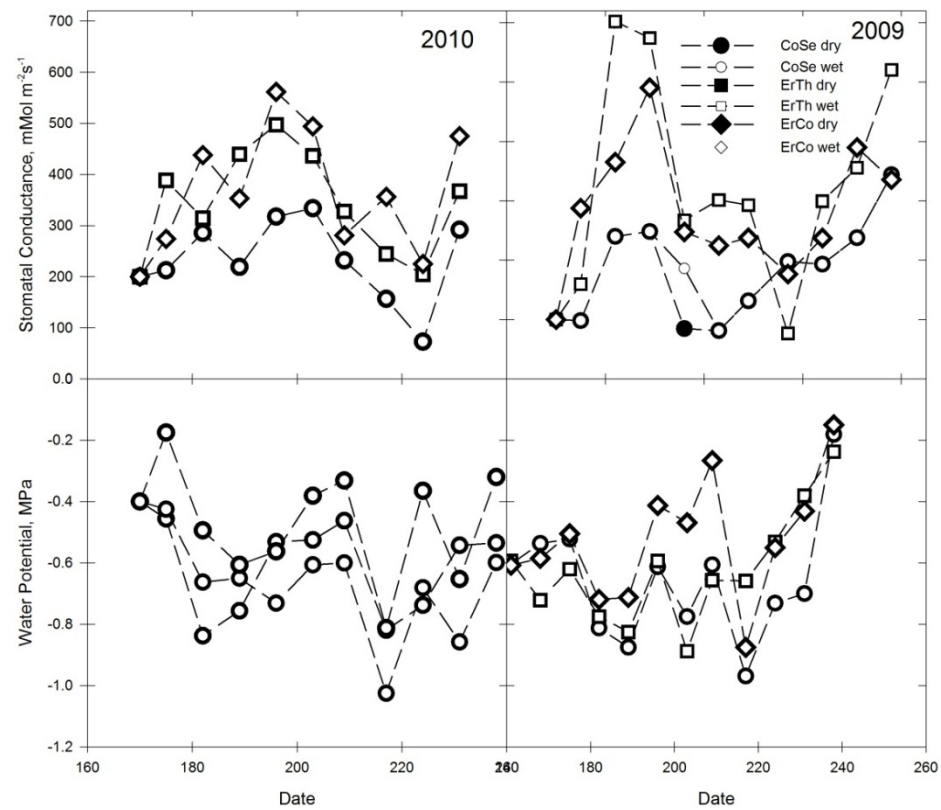


Figure 2. Stomatal conductance combined over 2009 and 2010 plotted against atmospheric vapor pressure deficit for *Eriogonum corymbosum*, *E. thompsoniae* and *Cornus sericea* 'Kelsey' either irrigated once every three days or not irrigated when growing in a field soil.

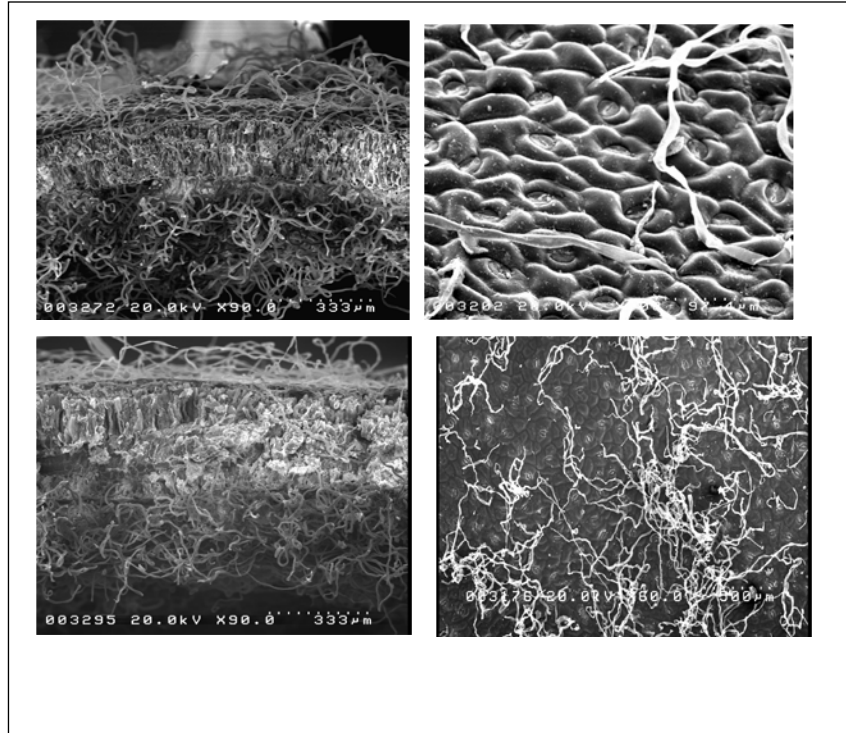


Figure 3. Scanning electron micrographs of leaf cross section (left) and top epidermal layer with stomatal (right) for *E. thompsoniae* (top), *E. corymbosum* (bottom).

CHAPTER IV.

EVALUATING *ERIOGONUM CORYMBOSUM* FOR SIGNIFICANT
MORPHOLOGICAL VARIATIONS FOR POTENTIAL CULTIVARS

ABSTRACT

Lacy Buckwheat (*Eriogonum corymbosum* Benth) has many aesthetic qualities such as late season blooming yellow and white flowers, long bloom times and an interesting hemispherical crown shape, in addition to being drought tolerant, which make it a worthy choice for low water landscaping in the Intermountain West. Low water landscaping is an alternative sustainable approach to water conservation in irrigated urban landscapes. This study investigated the morphological diversity of thirteen *Eriogonum* accessions collected in the state of Utah and established in a common garden. Nineteen different variables made up of both quantitative and qualitative morphological characteristics comprised of leaf, canopy and floral characteristics were selected to compare between and within accessions. These characteristics were observed or measured then used in a Multidimensional Preference Analysis (MDPREF) to facilitate the selection of potential cultivars. The MDPREF is useful in selecting accessions with unique combination of ornamental characteristics that could have a marketable advantage.

INTRODUCTION

Drought cycles and population growth in the arid Intermountain West (IMW) demand a more sustainable approach for irrigated landscape watering practices. Irrigated urban landscapes can consume up to 60% of municipal water supplies in the IMW (Kjelgren 2000). Water conservation in irrigated urban landscapes is a critical aspect of managing growth and drought cycles (St. Hilaire 2008).

Low water landscaping is an alternative sustainable approach to water conservation in irrigated urban landscapes. Low water landscaping is the careful design of irrigated landscapes for non-uniformity of surface cover using fewer and yet more drought tolerant plants (Mee W 2003). Native IMW plants from lower elevations are typically drought tolerant and many have aesthetic qualities suitable for urban landscapes. Drought tolerant plant species from the IMW often have deep, extensive root systems and fine-textured small leaves that intercept less sunlight due to attractive blue-green or silver pigmentation that reflects more shortwave radiation, dense trichomes, or a waxy cuticle to reduce transpiration and soil water use. However, these species are infrequently used in urban landscapes because of limited nursery production and information on proper management in the landscape (Meyer and others 2009).

Low water landscapes also conserve water through proper management. Supplemental irrigation in low water landscapes is typically only needed and applied during the heat of the summer, which eliminates the need to adjust the frequency of irrigation during the cooler spring and fall seasons (St. Hilaire 2008). Irrigation controllers can be set to operate based on hydrozones consisting of plants with similar water requirements, such as drought tolerant IMW natives. Water distribution uniformity

is a much less critical issue, as the large root systems of plants adapted to local conditions can take up water from a point source input and redistribute it internally to the plant and root system. Owner input and knowledge of irrigation controllers for low water landscapes can be potentially reduced to knowing when it gets hot, turn the system on and when it cools off, turn the system off (Kilgren 2010).

To reduce the amount of water used in the landscapes of the IMW a new palette of drought adapted plants is being established. These plants need to be evaluated at several levels before being released commercially. How unique are they? Are they potentially invasive? Can they be easily propagated? Can they tolerate more fertile and wetter landscape conditions? These questions and many more need to be addressed when introducing new plants to the landscape. No issue is more critical for introducing these species into low water landscapes than understanding their tolerance to both drought and frequent irrigation in the landscape.

The IMW has many ecological niches due to steep elevation, recent glaciation, and a wide variety of parent materials that allow plant colonization and speciation. This diversity in ecological niches has resulted in habitats that have given rise to many endemic and rare plants (Shultz 1993).

A plant's ability to adapt gave it an advantage for filling those new available niches. Plants species that experience rapid speciation have the ability to exchange genetic information with other similar species through introgressive hybridization (Grant and others 2005). Intermountain West genera like *Eriogonum* and *Penstemon*, which fit into this category, show a vast amount of morphological variation. This variation is a resource that can prove valuable in cultivar selection for landscape plants.

Eriogonum corymbosum is a shrub endemic to very dry habitats in the Colorado Plateau region of the IMW. *Eriogonum corymbosum* has many aesthetic qualities in addition to being drought tolerant, such as long duration late season blooming of yellow and white flowers, and an interesting hemispherical crown shape. *Eriogonum corymbosum* is being propagated for commercial release as a low water ornamental plant. There is no question that its uniqueness draws interest from native plant horticulturalist and enthusiasts. But can *E. corymbosum* become a major plant for low water landscapes of the IMW and beyond or will it be relegated to rock gardens and other esoteric uses? A major issue before *E. corymbosum* can be introduced into low water landscapes is its genetic variation. The genetic stability of its wide range of flower color, duration of flowering, and variability is unknown. Is the morphologic variation between populations of *E. corymbosum* due entirely to genetics? What effect would a common environment have on the ornamental significant morphology of several populations of *E. corymbosum* collected from across the Colorado Plateau? The objectives of this study are:

1. Quantify the range of morphological characteristics of *E. corymbosum*
2. Systematically evaluate common garden accessions based on morphological characteristic for potential cultivar development

MATERIALS AND METHODS

This study investigated the morphological diversity of thirteen *Eriogonum* accessions collected in the state of Utah. The collection sites were throughout and adjacent to the Colorado Plateau (Figure 4). The seed for each accession was collected in the fall of 2005 and the fall of 2006. The seed for each accession was cleaned and placed in petri dishes between two pieces of moistened blotter paper then placed into cold stratification (7° C)

for 6 weeks. During that 6-week period the seed was kept moist and checked for seedling emergence. After stratification all seedlings were planted into a 6.35 cm x 6.35 cm x 6.985 cm container using Sunshine #1 soil media. When the first containers were filled out with roots, the plants were moved into a 9.2075 cm x 9.2075 cm x 15.24 cm container with custom soilless substrate (4 parts sieved peat, 4 parts vermiculite, 2 parts Turface (montmorillonite clay), 2 parts #16 quartz silica sand) and fertilized with Osmocote Plus Fertilizer (The Scotts Company LLC, Marysville, Ohio) at a rate of 1 tablespoon per gallon pot size soil. All seedlings were kept in a greenhouse until needed for field planting.

The seedling plants were installed in early spring 2007 into a common garden at Utah State University Greenville Experimental Farm in North Logan, Utah on a Millville silt loam (coarse-silty, carbonatic, mesic Typic Haploxerolls) with very high water holding capacity. The seedlings were planted on center with one meter between plants and 1.5 meters between rows. Five plants from each accession were planted in blocks within the row. During the course of the study the rows were irrigated with 2 (4L/hr.) drip emitters per plant for 2 hours per irrigation on a 21 day schedule. The flower stalks were pruned off every fall after dormancy. No fertilizers were used.

Morphological Traits

The common garden collection of *E. corymbosum* allowed the many different leaf sizes and shapes, canopy characteristics, and flowering traits to be evaluated under a common set of conditions and optimum plant growth. Nineteen different variables made up of both quantitative and qualitative morphological characteristics were selected to compare between and within accessions. Characteristics chosen for study were based on

an ornamental trait deemed desirable. Qualitative characteristics were scored as binary states (present/absent) or unordered multistate characteristics (heavy, medium, light), whereas quantitative characteristics were either measured or counted and scored as continuous characteristics. The procedure for evaluating the different types of characteristics included:

- Leaf characteristics. Five mature leaves were measured then averaged or observed per plant for each accession for these quantitative and multistate characteristics.
 1. Leaf length - (quantitative) measured with metric ruler once, midsummer 2009
 2. Leaf width - (quantitative) measured with metric ruler once, midsummer 2009
 3. Petiole length - (quantitative) measured with metric ruler once, midsummer 2009
 4. Abaxial leaf pubescence - (multistate) comparative observation once, midsummer 2009
 5. Adaxial leaf pubescence - (multistate) comparative observation once, midsummer 2009
 6. Leaf shape - (multistate) comparative observation once, midsummer 2009
 7. Foliage color - (multistate) comparative observation once, midsummer 2009
- Canopy characteristics. All the plants for each accession were measured then averaged or observed for these quantitative and multistate characteristics.
 8. Canopy width - (quantitative) measured with metric ruler once, midsummer 2009

9. Canopy height - (quantitative) measured with metric ruler once, midsummer 2009
10. Canopy density - (multistate) comparative observation once, midsummer 2009
11. Canopy form - (multistate) comparative observation once, midsummer 2009
12. Canopy fall color - (multistate) comparative observation once, midsummer 2009
13. Flower stem length - (quantitative) measured with metric ruler once, midsummer 2009
14. Leaf stem length - (quantitative) measured with metric ruler once, midsummer 2009
- Floral characteristics. All the plants for each accession were measured or scored then averaged or observed for these quantitative, multistate and binary characteristics.
15. Date of initial bloom - (quantitative) date recorded upon the first flower opening, once 2009
16. Flowering period - (quantitative) date recorded when the first flower fades to fall color, once 2009
17. Flower color - (multistate) measured with metric ruler once, midsummer 2009
18. Red pigmentation in flowers - (binary) observation on tepals, midsummer 2009, verified midsummer 2010
19. Male sterility - (binary) observation of stamens midsummer 2009, verified midsummer 2010

DATA ANALYSIS

Accession Traits

The nineteen different morphological traits can be divided into three reasonably cohesive categories. The leaf traits (Table 2) have some ornamental value but the leaves typically disappear for most accessions behind the flower stocks early in the summer. The leaves also help with identifying each accession. The canopy traits (Table 3) are more ornamental, especially the size, form, and fall color characteristics. Leaf stem and flower stem lengths were collected because, again, it was considered useful in variety identification. The flower traits (Table 4) are highly ornamental and their diversity provides several different combinations that both extend and enhance the value. When all nineteen traits are considered along with their multiple levels a substantial amount of information exists for analysis.

Nonlinear Principal Component Analysis

A Multidimensional Preference Analysis (MDPREF) (PROC Prinqual, Ver. 9.2, SAS Inc., Raleigh, North Carolina) was used to explore nonlinear combinations of the original variables. The SAS procedure PRINQUAL essentially is Nonlinear Principal Component Analysis with the option of variable transformation. This nonlinear PCA (categorical) was required to incorporate and handle nominal and ordinal data types within the examined dataset. The continuous variables were transformed as if they were ordinal (Linting 2007), thus the observed variables can be referred to as a category, making comparisons possible. This monotone transformation is a non-metric transformation that weakly preserves order and category ties. It was preferred over other options as it explained more variance.

A simple line plot which plots the number of eigenvalues against their values graphically determines the optimal number of PCs to retain for analysis. This plot is known as a scree plot and it finds the place where the eigenvalues level off to the right of the plot. The eigenvalues in this smooth section are considered “scree” and the variance of these eigenvalues is insignificant. A scree plot for this analysis indicated that five PCs should be kept for analysis and that they accounted for 94% of the variance.

Taxonomic Classification

Determining the taxonomic classification for the accessions of the common garden proved no simple task. Like other *Eriogonum* species, *E. corymbosum* is comprised of many overlapping expressions making variety identification difficult. Key diagnostic characteristics like flower morphology are very similar between varieties. At the same time perianth color, which is used to group varieties, can be extremely varied within a given population. The same is true with leaf characteristics which are also important diagnostic keys (Reveal 2008). Reveal (2008) states that careful observation and note taking in the field is vital to proper identification. He recommends the combination of flower color, leaf features and geographic distribution to distinguish varieties.

Voucher specimens and field notes were collected both in the field during seed collection and from the common garden. These were compared with voucher specimens from the Intermountain Herbarium on the Utah State University campus in Logan, Utah. A dichotomous key for the family Polygonaceae (Reveal 2008) was used with all the other information to make a determination for each accession.

Ratings (Table 5) were developed for each accession based on key ornamental and physiological characteristics as well as known caveats. The length of floral display and timing were considered key ornamental traits. Latitude and elevation were also considered for potential cold and heat tolerances that could extend the range for a given cultivar. Known sensitivities to wet soils were noted as possible cause for the failure of a cultivar.

RESULTS AND DISCUSSION

The nineteen characteristics observed in this study represent substantial variation with regard to important ornamental choices for cultivar selection. Some traits stand out, some are less obvious. The leaf size and shape perhaps are not as noticeable as flower color differences but they do contribute to textural differences between accessions. The accession with the largest leaves have leaves that are four times the size of the accession with the smallest leaf. If size differences were not enough, there are four different leaf shapes. The shapes can be dramatically different. Accession Henryville has a linear leaf that is three times longer than it is wide. Accession Moab has an orbicular leaf as wide as it is long. There are also accessions with ovate and oblong leaves. The ovate leafed accession Springdale is the largest leaf in the common garden collection. It also has a long petiole which when coupled with the large leaf size results in possibly the most unique softer texture in the studied accessions. Leaf pubescence varied greatly between accessions. This characteristic was determined through side by side observations of the different leaves and then separated into like groups based on the density of the pubescence. The abaxial and adaxial sides were both considered separately. The density of abaxial surface pubescence of all accessions varied, but all were quite matted, creating

a considerable boundary layer that would restrict transpiration rates. The adaxial surface density was far more varied. Accessions with a thicker pubescence have a blue-green foliage color while those with a light pubescence were green. Each has its own appeal, but the leaves for all the accessions essentially disappear with the onset of the flower stocks that develop in early summer.

The canopy characteristics are important ornamental facets for this common garden collection. Generally, plant size can be split into accessions that at maturity exceed 100 cm and those that were around 80 cm in width. There were only two notable exceptions. Accession Goblin Valley measured only 39 cm in width. There was only one plant of this accession in the common garden and it appeared to be inconsistent with the size of the parent from which it was collected. The parent plant exceeded 100 cm in its native habitat. Accession San Rafael Swell #2 (SRS#2) was consistent with the parent population from which it was collected and its size, taken from five plants in the common garden, averaged 54 cm.

Canopy density was visually estimated based on 4 distinctive canopy densities of the common garden accessions. At the one end of the canopy density spectrum is accession Springdale, which has a light airy density that is very dissimilar to the other common garden accessions. At the other end of the spectrum, the SRS#2 accession was indisputably denser than any other accession.

Canopy form was considered as two distinctive categories: hemispherical and irregular form. Fall color of the plant varied with three shades of rust red, and one shade of brown. Although there are different color shades between accessions, each accession was consistent for one particular shade.

Floral characteristics are varied and are highly ornamental. The date of bloom for the accessions of the common garden spanned from mid-August to the end of September. These late flowering dates can provide color in the garden when little else is blooming. Bloom duration varied from 17 days to 55 days with most accession averaging over 30 days. Areas with longer growing seasons may see longer bloom periods than northern Utah. Flower color is generally either yellow or white for this species, but this accession exhibited two shades, a bright and a soft yellow. The bright yellow flower of the Henryville accession is unique and a real showstopper. It is not surprising that this variety, *E. corymbosum glutinosum*, has already been released in the trade. The soft yellow color of accession Shivwits is also appealing and worthy of consideration. The white flowered varieties, attractive on their own, also showed different degrees of red pigmentation. Red pigmentation in *E. corymbosum* is a desirable ornamental trait. Although the flower tepal (fused sepal and pedal) color in most accessions is white, red pigmentation on the calyx portion of the tepals, stamens and veins of the petals can give the flower a pink to red coloration. The presence and degree of red can vary greatly between individuals within an accession as well as between other white tepal colored accessions.

Early observation of *E. corymbosum* indicates that it may express male sterility in many of the different observed populations. This has been observed both in the common garden and in the population's natural habitat. This expression of sterility for *E. corymbosum* has not been cited in any literature reviewed. At this point it is uncertain if this sterility is genetic, cytoplasmic or environmental. Genetic male sterility has been observed in at least one other *Eriogonum* species, *Eriogonum ovalifolium* var.

williamsiae (Archibald and others 2001). Genetic male sterility is a characteristic that can be used to advantage in the production of hybrid cultivars (Fehr 1993).

One forewarning that cannot be overstated is *E. corymbosum* sensitivity to water saturated soils. Fifty-seven plants were planted into the common garden in summer of 2007. Before the study began in 2009 the common garden had suffered 5% mortality. The study started in June 2009 and when the season ended in mid-November no more plants died. In June 2010 when the study resumed there was a 33% mortality rate. Anecdotal evidence would suggest the high mortality was due to unseasonably high late spring rainfall both years and the resulting saturated silty loam soils of the plot site. Over the same period of time, *E. corymbosum* plants that were located in other nearby sites with better drainage did not have any problems.

Multidimensional Preference Analysis

The results of the MDPREF are graphically represented by biplots of the preference space (Figure 5). These biplots reveal the relationships between the individual accessions and the observed characteristics by projecting the observed characteristics onto the plane in the transformed variable space. Analysis of the five PCs retained for analysis resulted in 10 biplots for interpretation purposes.

Unique morphological characteristics often provide a marketable difference for a cultivar. Uniqueness in the biplot shows up with accessions in extreme positions or the last accession on the X or Y scales either positive or negative. They often pair opposite of accessions with the opposite extreme for a strong loading characteristic, making comparisons obvious. If the characteristics have noteworthy application for a cultivar then the accession should be considered. The MDPREF will not pick the perfect cultivar

but it may prevent overlooking something of potential importance in a highly variable species like *Eriogonum*.

The biplot in PRINQUAL is simply the PRINCOMP “component pattern” plot laid over the “component scores” plot. The length of the vector arrows indicates the influence (variance) that vector has on that dimension. A biplot plotting PC 1 against PC 2 explained 56% of the variance in the study. PC 1, which occupies the X axis in this biplot, has 35% of the variance and loads strongly with crown structure which refers to the density of the crown after it has produced flower stalks. This measurement is qualitative and was made through observation. On the positive end of the X axis is the relatively light and airy crown of accession #149 and on the negative end is the extra dense crown of accession #511. PC 1 also loads strongly with the quantitative variable “leaf length.” This strengthens the separation of accession #149 which has the longest leaf from accession #511 which has one of the shortest leaves. Strong negative loadings say as much as positive loadings. PC 1 has a strong negative loading for the density of the variable “pubescence on the top of the leaf.” This negative loading also strengthened the separation of accessions with #149 having the lightest and #511 having among the heaviest pubescence on the top of the leaf. This also illustrates the need for dynamic decision making with interpretation. A thicker pubescence enhances a blue green foliage color. However, a thicker pubescence could also improve drought tolerance. This particular negative loading resulted in two different analysis levels to consider.

PC 2 has a strong loading for flower color and a strong negative loading for days in bloom. Accession #150 stands alone in the negative Y axis of this dimension. This position is indicative of several things. It has the longest number of days in bloom of all

the accessions at 55 days. It is the only accession to have a less desirable brown fall color. It is one of only three accessions to possess the more irregular form exhibited. This is verified by examining the biplots where the vectors for these characteristics have a negative direction on the Y axis and the length of the vector arrow shows that their variance is having a strong to moderately strong influence in this dimension. The strong loading for flower color also strengthens the extreme position that accession #150 occupies. It is the only accession to have the bright yellow flower color. The rest of the accessions occupy a relatively narrow band on the Y axis. With careful interpretation each of the ten biplots reveals the relationships between the accessions and the characteristics. Each biplot results in new ways to assess and understand these relationships.

Taxonomic Classification

At this point it needs to be stated that no claims are being made as to the exact variety or even species everything in the common garden study truly belongs too. There are those that quite clearly identified, based on their morphology and where they were collected. However, other selection originated in areas where varieties overlap and have morphological characteristics that overlap. There are at least two more species other than *E. corymbosum* in the common garden collection. One is *Eriogonum thompsoniae*, while another is likely *Eriogonum smithii*. Both were mistakenly collected as *E. corymbosum*. There are still other common garden selections that defy identification. ErCo #506 and #518 were collected east of Zion National Park and north of Mount Carmel Junction, respectively. If they are in the *E. corymbosum* complex they would be in an area known for the variety *glutinosum*. But they do not resemble *glutinosum* in any way. Their leaves

resemble *E. thompsoniae* but without the long petiole or the flatter leaf of *E. thompsoniae*. This would be interesting, but both varieties fall short from an ornamental perspective with flower period length and form issues making them unsuitable for cultivar selection. Two more varieties (ErCo #523 and #525) that are within a close geographic location of each other (Hell's Backbone Highway 10 and Long Canyon, Burr Trail) pose a problem; this area overlaps the habitat for var. *corymbosum* and var. *orbiculatum*, and these two varieties have little in common. If identification was based on leaf shape alone, Hell's Backbone would be var. *orbiculatum* and Long Canyon would be var. *corymbosum*. Instead, Hell's Backbone has the right leaf shape but is one half the size of other known var. *orbiculatum* in the common garden; even with that large difference it falls within the range given by Reveal's (Reveal 2008) dichotomous key for this species. #525 has a leaf that fits the var. *corymbosum* key characteristics, but the size of the plant is one third larger than the var. *corymbosum* of the San Rafael Swell (accessions #510, #511) or Flattop Butte (accession #147). This size difference is also seen in their native habitats. This identification issue gets more interesting as these two varieties are among those with the greatest ornamental value.

It is believed that four of the eight identified varieties are present in the common garden study.

1. Common garden accession Henryville (#150) is a selection of *E. corymbosum* var. *glutinosum*. *E. corymbosum* var. *glutinosum* is conspicuous from the other varieties with its bright yellow flowers. This variety has no red pigmentation. It blooms from mid to late August and the flowers stay attractive for several weeks. This variety was collected near Henryville, Utah,

and was the first commercially available selection for this species. This is a large variety averaging 1355 mm width but with a low average height of 518 mm, giving this variety a ground cover appearance, to a certain extent. Var. *glutinosum* also addresses another of the *E. corymbosum* caveats: when this accession is isolated it produces seed that is true to flower color. As discussed previously, white flowered *E. corymbosum* plants vary as to how much red each individual will express. This trait could be difficult to control in seed production. Given the limitation that *E. corymbosum* is difficult to reproduce by cutting, a cultivar that would come true to seed would be very desirable. Var. *glutinosum* has a brown fall color.

2. *E. corymbosum* var. *aureum* is represented in the common garden by accession #602. This is one of the easily identified varieties. It is the only one that has glabrous flower stems. It occurs only in a small geographic location near Shivwits, Utah. It is also the only variety that came from a population that has plants with either yellow or white flowers. The yellow flower of this variety is very different from the brilliant yellow of var. *glutinosum*, as it is a soft pale yellow. The white flower, like the yellow, has no red pigmentation. This variety blooms later in the year than any of the others. It is close to the first part of October before this variety reaches full bloom. This population is a large variety at over 1000 mm in width and has an attractive form. *Aureum* has an attractive light-rust fall color.
3. *E. corymbosum* var. *orbiculatum* population is found in the southeast portion of the state. Common garden accession Moab (#527) was collected along the

Colorado River east of Moab. This is a large variety with white flowers and red pigmentation. Accession Hells Backbone (#523) is likely another “orbiculatum” and has a flowering duration of 48 days and a white flower. It has striking red highlights on the flowers that in the native population seem consistent for the amount of red pigmentation. It has not been tested to see if this red pigmentation is a true to seed characteristic.

4. *E. corymbosum* var. *corymbosum* is the common white flowered expression of the species. There are several recognized expressions within variety “corymbosum.” They are separated from each other mostly by leaf morphology: erect leaves (var. *erectum*), small crenulate leaves (var. *divaricatum*), There is also a hybrid between *E. corymbosum* and *E. brevicaule*. This diversity within the var. *corymbosum* helps explain the variation in the common garden. The range for this variety as reported by Reveal (2008) and Ellis (2009) is the largest geographic area going north into southwest Wyoming and south into northern Arizona, and including western Colorado as well as eastern and southeastern Utah. Accessions Flattop Butte (#147), Long Canyon (#525), San Rafael Swell #1 (#510), and San Rafael Swell #2 (#511) all appear to be var. *corymbosum*. Accession Flattop Butte is the most northerly located selection of the common garden collection. It was collected near Flattop Butte in the Duchesne/Roosevelt Utah area. It measures among the small statured plants in the collection. It shows a wide range of red pigmentation in the common garden. Accession #510 was collected in the San Rafael Swell, another of the small-statured accessions that strongly resemble

Flattop Butte, but with only one specimen that showed any significant red pigmentation. San Rafael Swell #2 (#511) was also collected in the San Rafael Swell. This accession is a very small plant with a very dense canopy and is a significantly different from San Rafael Swell #1.

Plant height and width for each accession can only be generalized as inadequate room was provided in the common garden to get an accurate measurement.

CONCLUSIONS

The morphological diversity in the *E. corymbosum* Greenville farm common garden offers several choices for cultivar selection. The following list will highlight these choices and attempt to explain why they are being considered. However, several other accessions show promise and could also be considered for their uniqueness. It should be noted that since *E. corymbosum* var. *glutinosum* has already been released into the trade it was not considered here, although it appears to be one of the varieties with tremendous potential.

- Accession Hells Backbone (#523) (Figure 6). The Hells backbone accession is one of the smallest accessions. This is one of the most visually appealing accessions. Its bloom date was September 6 and it has one of the longest bloom periods at 48 days. Due to poor germination for this accession there was only one plant in the common garden, so the statistics are compromised. The reasons for selecting this accession are based more on observations in its native habitat. The population where the seed for this accession was collected is consistent for red pigmentation. Being able to reproduce this accession from seed and still get a consistent red color would be desirable; this observation still needs to be verified

through further research. In the MDPREF analysis it stood out in all the biplots that include PC 1, PC 4 and PC 5. It was associated with a strong negative loading for the characteristics; leaf stem length, initial bloom date, abaxial leaf pubescence, fall color and petiole length. With the exception of initial bloom date the characteristics are not highly significant ornamental characteristics. The initial bloom date for this accession falls in the middle of this characteristics range. The advantage of a later bloom date would be extending the bloom period farther into the fall.

- Accession Long Canyon (#525) (Figure 7). The Long Canyon accession is a large variety with a consistent hemispherical form, white flowers and red pigmentation. If there is any truth in the saying “the exception that proves the rule” this accession is it. It did not stand out in any of the biplots in the MDPREF analysis; it is just an attractive plant, and when coupled with its relatively early bloom date of August 24 and its 40 day bloom that is enough to make it one of my top choices.
- Accession Flattop Butte (#147) (Figure 8). Flattop Butte is another of the small statured accessions. This attractive accession showed some of the best red coloration of all the accessions. It also grows in a more northerly location, possibly suggesting good cold hardiness. In the MDPREF analysis it stood out in all the biplots which included PC1. This biplot has a strong negative loading for abaxial leaf pubescence and fall color. Its dark rust fall color is characteristic of all the *E. corymbosum* var. *corymbosum* and is extremely attractive.

TABLE 2. Leaf characteristics (list) for *Eriogonum corymbosum* planted in a common garden at USU Research Farm.

Accession	Location	Leaf Length (cm)	Leaf Width (cm)	Petiole Length (cm)	Leaf Abaxial Pubescence	Leaf Adaxial Pubescence	Foliage Color
147	Flattop Butte	2.28	1.18	0.52	heavy	heavy	blue-green
149	Springville	5.28	3.1	6.14	heavy	light	green
150	Henryville	2.56	0.84	0.58	heavy	light	green
506	East of Zion	4.72	1.4	414	medium	medium	blue-green
509	Goblin Valley	4.72	0.66	0.94	medium	heavy	blue-green
510	San Rafael Swell	2.08	0.98	2.92	heavy	heavy	blue-green
511	San Rafael Swell	1.74	0.68	0.28	heavy	heavy	blue-green
518	Mount Carmel	5.14	1.34	5.8	heavy	medium	blue-green
520	Tropic	4.5	1.68	0.96	heavy	medium	blue-green
523	Hell's Backbone	1.44	1.6	0.98	medium	heavy	blue-green
525	Long Canyon	2.6	1.18	6.28	heavy	medium	blue-green
527	Moab	2.68	2.46	1	light	light	green
602	Shivwits	1.98	1.06	0.74	heavy	medium	green

TABLE 3. Form characteristics (list) for *Eriogonum corymbosum* planted in a common garden at USU Research Farm.

Accession	Location	Plant Width (mm)	Plant Height (mm)	Leaf Stem Length (mm)	Flower Stem Length (mm)	Canopy Density	Fall Color	Form
147	Flat Top Butte	730	351	98	160	tight	dark rust	hemispherical
149	Springville	1039	422	66	178	loose	light rust	hemispherical
150	Henryville	1355	518	157	162	medium	brown	irregular
506	East of Zion	1459	665	141	187	medium	light rust	hemispherical
509	Goblin Valley	310	290	146	161	medium	light rust	hemispherical
510	San Rafael Swell	776	413	136	112	medium	dark rust	hemispherical
511	San Rafael Swell	543	230	71	49	extra tight	dark rust	hemispherical
518	Mount Carmel	1268	700	175	195	medium	light rust	irregular
520	Tropic	1182	494	113	217	medium	med rust	irregular
523	Hell's Backbone	290	140	75	91	medium	dark rust	hemispherical
525	Long Canyon	870	404	146	161	tight	dark rust	hemispherical
527	Moab	980	449	161	259	tight	light rust	hemispherical
602	Shivwits	865	393	89.55	240.3	tight	light rust	hemispherical

TABLE 4. Flower characteristics (list) for *Eriogonum corymbosum* planted in a common garden at USU Research Farm.

Accession	Location	Flower Color	Red Pigmentation	Male Sterile	Bloom Date	Days in Bloom
147	Flat Top Butte	white	yes	yes	8/21/2009	37
149	Springville	white	no	no	9/17/2009	38
150	Henrieville	yellow	no	no	8/24/2009	55
506	East of Zion	white	yes	no	9/17/2009	17
509	Goblin Valley	pale-yellow	yes	yes	9/16/2009	32
510	San Rafael Swell	white	yes	no	8/29/2009	36
511	San Rafael Swell	white	yes	yes	8/29/2009	36
518	Mount Carmel	white	no	yes	9/16/2009	22
520	Tropic	white	no	no	8/23/2009	42
523	Hell's Backbone	white	yes	no	9/6/2009	48
525	Long Canyon	white	yes	no	8/25/2009	40
527	Moab	white	yes	no	9/16/2009	30
602	Shivwits	pale-yellow	no	no	9/27/2009	28

TABLE 5. Accession locations, ratings and notes for *Eriogonum corymbosum* planted in a common garden at USU Research Farm.

Accession	Location	Variety	Latitude	Longitude	Rating	Notes
150	Henrieville	glutinosum	N 37° 33' 50"	W -112° 02' 15"	1	An exceptional selection. Already in the trade. Caveat: extremely sensitive to heavy, water saturated soils.
523	Hell's Backbone	orbiculatum maybe velutinum	N 37° 48' 49"	W -111° 24' 32"	2	In nature the flowers appear in balls, not so in the common garden. Good potential for red flower highlights. Small size.
525	Long Canyon	corymbosum maybe velutinum	N 37° 51' 10"	W -111° 18' 45"	3	Beautiful, well-formed large variety.
147	Flat Top Butte	corymbosum	N 40° 13' 20"	W -110° 06' 17"	4	Small size, potential for cold hardiness. Found in nature at elevations above 2700 meter
602	Shivwits	aureum	N 37° 10' 56"	W -113° 46' 10"	5	Large plant. Unique soft yellow or white flower. Latest flowering date
149	Springville	E. thompsoniae	N 37° 11' 48"	W -112° 59' 34"	6	Unique airy form. Beautiful large plant. Caveat: extremely sensitive to heavy, water saturated soils.
527	Moab	orbiculatum	N 38° 37' 42"	W -109° 30' 17"	7	Beautiful large plant. Unique round leaf.
511	San Rafael Swell	corymbosum	N 39° 06' 26"	W -110° 40' 24"	8	Unique very small plant with extremely tight canopy. Rock garden!
510	San Rafael Swell	corymbosum	N 39° 04' 44"	W -110° 40' 06"	9	Small plant, great consistent form.
509	Goblin Valley	E. smithii?	N 38° 36' 22"	W -110° 41' 12"	10	A sleeper...pale yellow flower with red highlights.
520	Tropic	corymbosum	N 37° 37' 12"	W -112° 04' 40'	11	Caveat: form inconsistent
506	East of Zion	corymbosum?	N 37° 15' 43"	W -112° 47' 07"	12	Caveat; Very short flower duration, form inconsistent
518	Mount Carmel	corymbosum ?	N 37° 16' 26"	W -112° 38' 45"	13	Caveat; Very short flower duration, form inconsistent

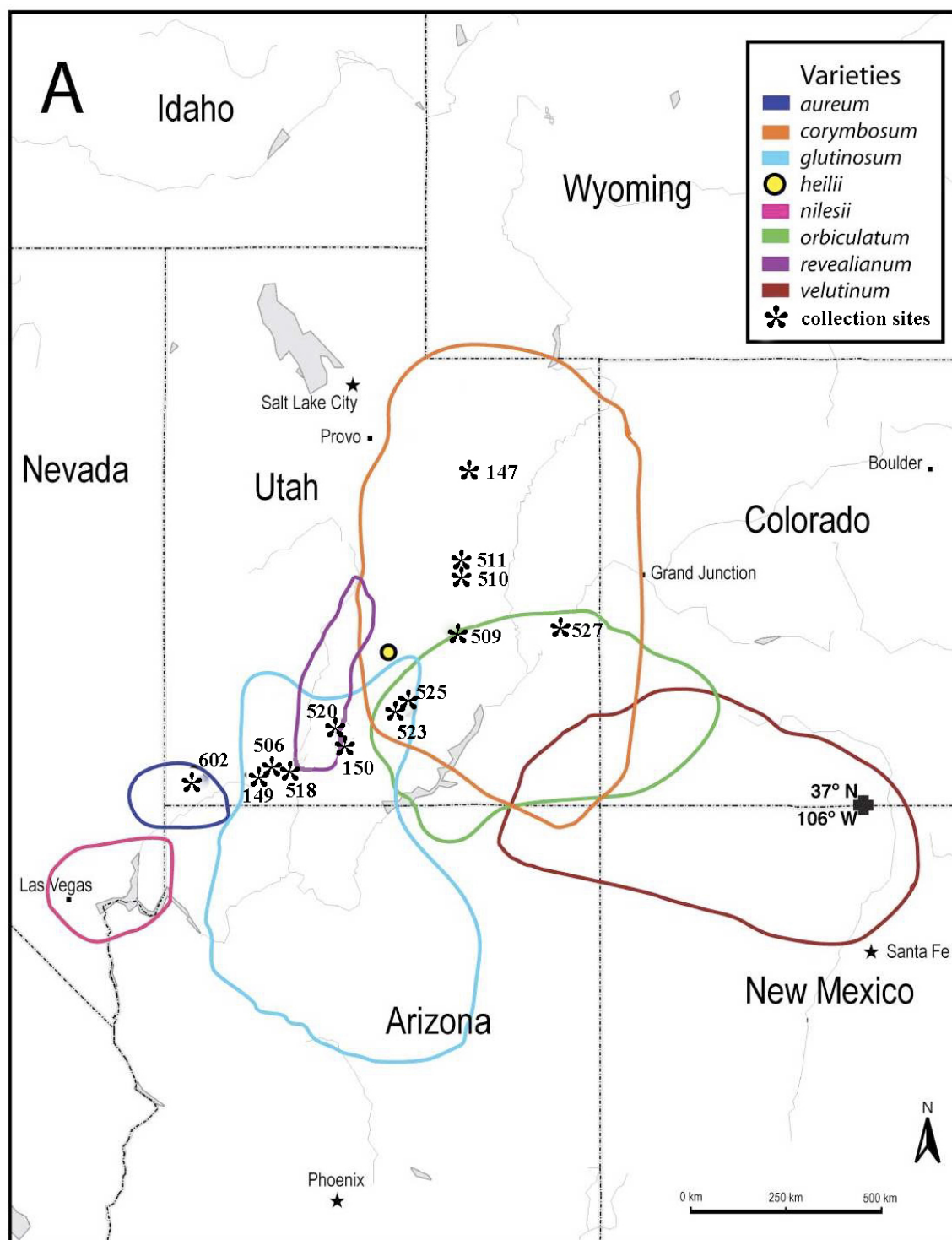


Figure 3. Ellis map depicting the general areas for each variety of *Eriogonum corymbosum* with the common garden accession collection sites overlaid.

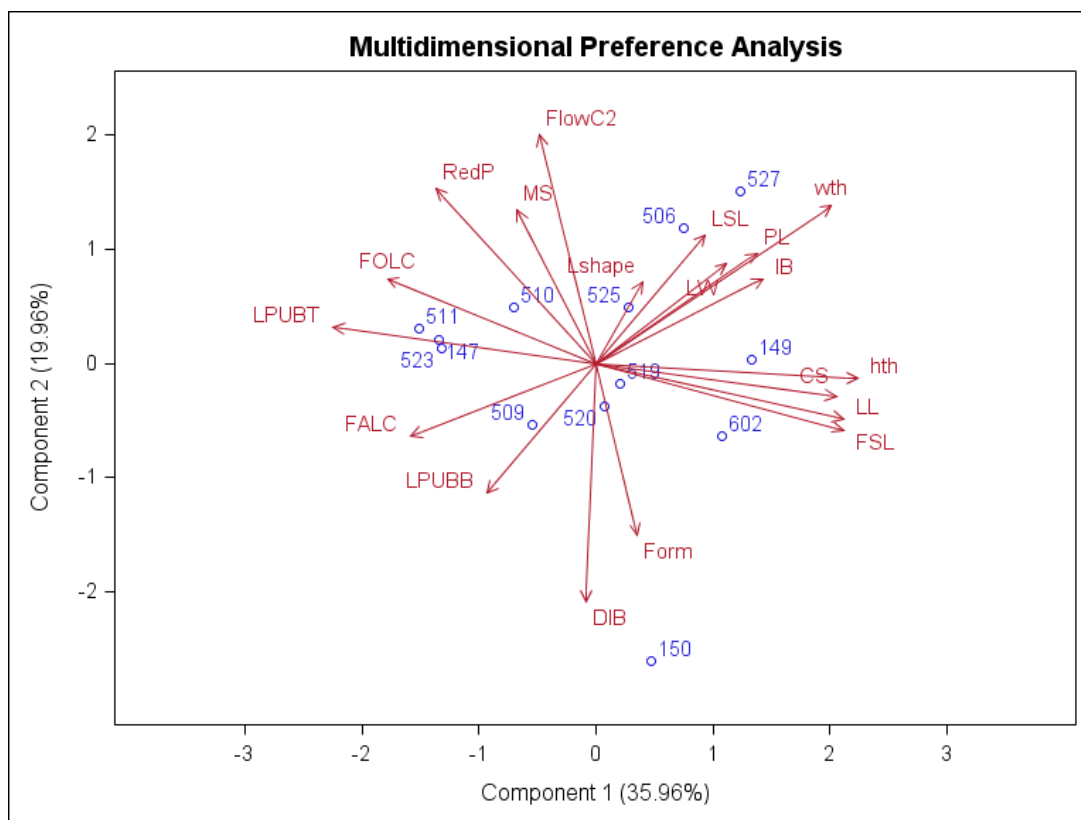


Figure 4. Multidimensional Preference Analysis biplot for PC 1 and PC 2. The biplot in PRINQUAL is simply the PRINCOMP “component pattern” plot (vectors) laid over the “component scores” plot, providing an easy comparison between the accessions and their preference for the different “component pattern” categories.



Figure 5. *Eriogonum corymbosum* accession #523 collected along Hell's Backbone, Utah, planted in a common garden at USU Research Farm.



Figure 6. *Eriogonum corymbosum* accession #525 collected in Long Canyon, Utah, planted in a common garden at USU Research Farm.



Figure 7. *Eriogonum corymbosum* accession #147 collected on Flattop Butte, Utah, planted in a common garden at USU Research Farm.

CHAPTER V

OVERALL CONCLUSIONS

Eriogonum corymbosum is a species that can add interest to low water landscapes throughout the IMW. The Colorado Plateau origins ensure a genetic predisposition for drought tolerance, and it stands out as an ornamental species due to the hemispherical form and brilliant long lasting floral display. Its morphological diversity provides many different choices for cultivar production, including filling a landscape design niche for a subshrub that can survive in low water landscapes throughout the IMW while providing three seasons of ornamental interest. With adequate drainage, *E. corymbosum* can also withstand excessive landscape irrigation practices. This could prove advantageous as both professional irrigation managers and homeowner become accustomed to newer, more sustainable watering practices. There are caveats associated with the introduction of this species as a landscape plant. In the landscape it must never be planted in soils that remain water saturated for any period of time; soils have always contributed to the health and visual success of plants in the landscape. Most drought tolerant plants for IMW landscapes, including *E. corymbosum*, will survive in a myriad of soils but will be challenged by high clays contents, water saturated soils, and high water tables. This presents a common sense issue that can be overcome through education. A more pressing concern exists at the nursery level for *E. corymbosum* success in the landscape, as it is difficult to propagate asexually. No formal studies have been done on producing cuttings from this species; however, anecdotal evidence suggests that there is a very low success rate with traditional “dip and stick” cutting techniques. *Eriogonum corymbosum* is a

prolific seed producer but it may prove difficult to produce a consistent flower color through seed propagation. The need for a consistent flower color is clearly an area where market research is needed. This, again, is an obstacle that can be overcome with more study. Another challenge may be protecting the small varied populations of this species from unscrupulous native seed harvesters. *Eriogonum corymbosum* var. *nilesii* is an endangered species. *Eriogonum corymbosum* var. *aureum* and var. *heilii* are very small populations and considered rare expressions. Rare expressions of other visually similar species like *E. smithii* and *E. thompsoniae* could also be at risk from increased interest in *E. corymbosum*. A sustainable approach to propagation could mitigate this and eliminate the economic incentive for native seed harvesting of this unique species.

Issues aside, *E. corymbosum* is already being successfully used in low water landscapes. The IMW is faced with water issues that are not going to go away. A new landscape “Genius Loci” needs to be defined that reflects the climate as well as the natural beauty surrounding it. A palette of low water native and adapted species including *E. corymbosum* will move the landscape industry in that direction, conserve water, and benefit homeowners and professional alike.

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